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MITIGATING CONDENSATION

PROBLEMS IN RURAL NORTHERN HOUSING

June 1991

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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FOREWORD

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EXECUTIVE SUMMARY

Extremes of climate have always had a punishing effect on Canadian buildings. This is perhaps nowhere more evident than in residential building stock which suffers from a general lack of technical advancement, often inadequate quality control and interior environmental conditions which fluctuate widely and are often aggravated by the unique requirements of diverse cultural groups. This combination of conditions exists in many rural, northern Albertan homes which have been built by semi or even unskilled forces, utilizing designs more suited to a southern, urban and mainstream use. The occupants of these homes often come from the native tradition with its long history of a water-based cooking regime. When coupled with the internal storage of water and firewood, the skinning and preparation of game, limited or non-existent water services and intermittent wood heat, a high humidity environment is generated within a poorly sealed and insulated building envelope. This combination invariably leads to both interior surface and interstitial condensation with resulting problems of surface damage, mildew, rot and general building decay.

OBJECTIVE

The objective of this project was to explore the issue of condensation in northern homes, and identify, test and evaluate mitigation strategies. Working with the staff of the Rural Home Assistance Program (RHAP) of Alberta Municipal Affairs, the project team explored these issues over a two year period. With the cooperation of a number of affected homeowners successful strategies for the active removal and continuing control of damaging excess indoor humidity were developed.

WORK PROGRAM

With the assistance of the RHAP staff, houses which were known to suffer from high humidity and condensation problems were identified in the Gift Lake and Wabasca areas. Following site visits, visual inspections, and condensation problem analysis, homes were selected for monitoring over one heating season. Temperature and humidity were recorded over the winter of 1988-89 to establish base indoor and outdoor environmental conditions.

Based upon a subsequent analysis of the recorded data and interviews with the residents, three homes were selected for the testing and evaluation of three alternative humidity mitigation strategies. Because of the relatively remote location of the homes, the systems were designed to meet three primary criteria:

i) the systems must be relatively maintenance free and automatic in operation;

ii) the strategies must not require a lifestyle change by the residents;

iii) the systems must be both economical and cost-effective.

Three systems which were thought to meet these criteria were devised:

i) the fresh-air intake of a forced-air furnace was increased;

ii) a variable-rate, pre-heated make-up air unit was installed with a direct feed to the living areas;

iii) the stack effect in a naturally ventilated, wood stove heated home was increased.

FINDINGS

All three systems were found to lower the relative indoor humidity, but at various costs:

i) modifications to the furnace to increase the fresh-air intake compromised furnace performance.

ii) noise, insufficient heating capacity and inadequate airflow rates were some of the problems found in the first three prototype make-up air units;

iii) natural stack ventilation was capable of reducing indoor humidity but it was too inconsistent in its operation to be recommended as a viable option.

CONCLUSIONS

The electrically powered make-up air unit (method #2) was the most dependable and effective way to reduce indoor humidity and minimize condensation damage. For a household with nine occupants, fan operation and electrical preheating of the air supply would cost about $15.00 per month. As well as reducing condensation damage, the make-up (fresh) air improves indoor air quality and counteracts chimney backdrafting.

1.0 INTRODUCTION

1.1 Purpose of Study

This study addressed building deterioration caused by high indoor humidity in some houses located in remote northern communities. The detailed objectives of this project were as follows:

- investigate the sources of high humidity in selected "problem" houses;
- determine the extent of damage caused by condensation;
- develop and implement alternative retrofit measures in existing houses to minimize condensation damage;
- determine the effectiveness of various retrofit measures implemented and monitored in this investigation.

1.2 Scope and Focus

The work looked at the problem of active migration of humidity in small wood framed homes in northern Alberta and explored options which are consistent with prevailing construction norms and local lifestyles. It focused on a series of approximately 100 m^2 bungalows which were built with assistance from the Rural Homes Assistance Program of Alberta Municipal Affairs.

The solutions were specifically designed to require little or no intervention by the occupants, while respecting their traditional lifestyle. All systems focused on the use of cold, outdoor air as a drying agent, but varied in delivery mechanism. Because humidity removal is in itself an energy consuming activity the systems shared similar operating costs. Therefore, efforts focussed on effectiveness, reliability and occupant comfort.

1.3 Organization

The remainder of this report is divided into five primary sections. Chapter 2 reviews condensation in northern housing from a historic and literary perspective. Chapters 3 and 4 discuss the theories of moisture generation and removal respectively. Chapter 5 details the installation, observations and evaluations of the three alternative mitigation systems that were tried in different homes. The conclusions and recommendations are contained in the final chapter. The report contains numerous tables and figures in support of the text.

1.4 Previous Efforts & Status of Issue

Recent advances in residential building technology have resulted in the construction of more air-tight houses. While these advances have resulted in lower heating costs, they have also led to problems with air quality and moisture because the heating and ventilating systems do not adequately serve "tight" houses. Many remote northern communities do not have conventional heating systems in their homes; in fact, most do not have forced air heating systems, relying instead on wood stove systems which have no forced air component and utilize natural convection currents to disperse the heat. Intermittent heating systems and excessive humidity cause condensation, mildew and structural deterioration.

Condensation causes serious deterioration to the building enclosure and many houses built in the early 1980's are exhibiting this problem. In 1986, the author conducted a study for the RHAP [1] and the Rural Home Emergency Program (RHEP) [2] to identify the extent of condensation damage, determine its cause and recommend remedial measures. The 1986 study found four major causes of condensation: occupant lifestyles, absence of water supply, poor sewage disposal and a lack of ventilation.

Most of the recommendations from the 1986 study have been incorporated into recently built houses. Houses built prior to 1986 have been modified to minimize condensation. Water and sewage disposal systems were installed to reduce indoor humidity and condensation. Condensation has successfully been reduced, but some new and old homes continue to exhibit some condensation damage.

1.5 Data Sources, Research Methods, and Treatment of Findings

The research team worked closely with local Slave Lake RHAP staff. RHAP housing officers frequently visit the rural communities and understand the local climate, construction details and occupant lifestyles. The RHAP staff also helped to select sites, obtain permission to investigate and assisted with monitoring equipment. RHAP staff were briefed on remedial measures before any installations were undertaken. At least one RHAP staff member was present during all installations and site visits.

The effectiveness of the retrofitted measures are most important. Before and after retrofits, homes were monitored to determine indoor and outdoor temperatures and relative humidity. Power consumption was also carefully measured in a home retrofitted with an electric make-up air unit.

2.0 CONDENSATION IN NORTHERN HOUSES - A HISTORIC AND LITERARY PERSPECTIVE

2.1 Literature Review

The problem of condensation in houses has been documented in publications from researchers, builders and all levels of government [3,4,5,6,7]. Results from research in the Northwest Territories [8,9,10] on passive, semi-passive and active ventilation are useful, but not encouraging. A literature review provided material on a range of remedial measures. Based on an analysis of their cost effectiveness and applicability to the study units, three were chosen for this study.

The majority of new houses built under the Rural Home Assistance Program (RHAP) do not have serious condensation problems. The success is attributed, in part, to the following strategies which have been used to address common problems and sources of humidity.

2.1.1 Water Supply and Sewage Disposal

Some older houses used to, and some still do, use 45 gallon drums as water cisterns, which increases humidity within the house. However most new and existing houses have a water supply system. If wells are not feasible, an 8000 litre (1800 imperial gallon) water tank is typically buried alongside the house and water is supplied by truck. In addition, hot water tanks eliminate much of the humidity that had previously been generated by boiling water on the stove.

Humidity also resulted from standing waste-water because no convenient means of disposal was available. This problem was eliminated in most cases by installing an inexpensive 1800 litre (400 gallon) minimum capacity septic system. Through the RHAP program, water supply and drainage systems have been installed in almost all new and existing houses.

2.1.2 An Open Floor Plan

In remote locations, some older houses are heated with wood burning stoves. The stoves are located in living rooms, but a lack of air circulation and presence of long corridors usually prevent heat from reaching the bedrooms. Consequently, living rooms are overheated in order to warm the bedrooms (see figure 1). Without air

circulation, humid air concentrates in bathrooms and kitchens, causing extensive condensation damage. Mold growth on the exterior corners of bedrooms is evidence of high indoor relative humidity.

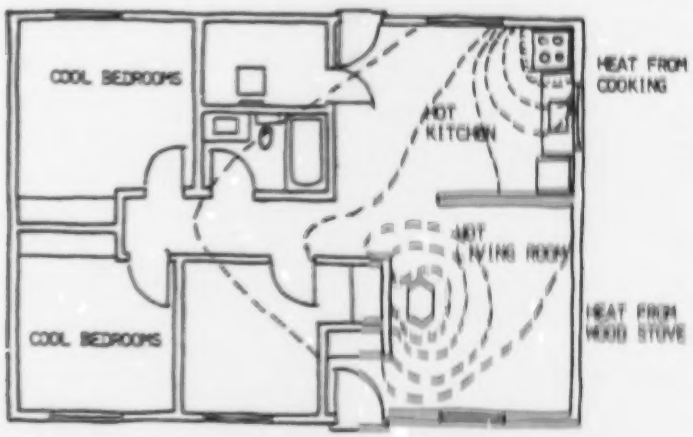


Fig. 1: Lack of Air Circulation Resulting in Concentrated Areas of Heat

In spite of the provision of forced-air furnaces in new houses, the high cost of heating fuels often limits their use. In addition, there is an abundance of free firewood for wood burning stoves. Without a substitute for the furnace fan, wood heat cannot be effectively distributed throughout the house.

Figures 2 and 3 indicate floor layouts that have been re-designed by RHAP personnel to facilitate the natural flow of air and heat. By eliminating the wall between the living room and kitchen, heated air from wood stoves can spread further.

2.1.3 Entrance Vestibule

Moisture is often brought into the house by tracking in snow, water and dirt. An enclosed vestibule that functions as a mud room will act as a buffer and moisture evaporation will occur outside the home. In most new houses an enclosed entrance vestibule for the most commonly used door is now incorporated. As shown in figures 2 and 3, below, the vestibules provide an energy conserving airlock and serve as a mud room where

wet clothes, boots, firewood and meat can be hung to dry. The vestibule is very effective in preventing most moisture from reaching other parts of the house.

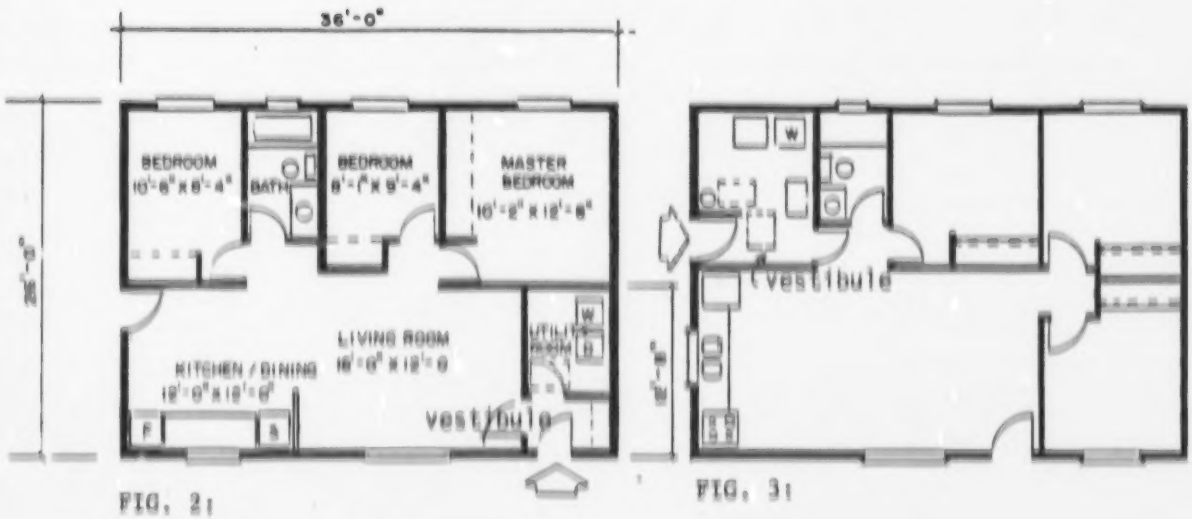


FIG. 2:

FIG. 3:

Fig. 2 & 3: New Floor Layout with Enclosed Entrance Vestibule and Open Floor Plan

2.1.4 Exterior Attic Access Hatch

Attic condensation in some older houses is also a concern. Air leakage from ceiling attic access hatches allows warm moist air into the attic where it condenses. Early efforts to correct this problem through the use of rigid insulation often proved fruitless because the rigid insulation used on the hatches left a thermal weakness (gap) between the insulation and hatch opening (see Figure 4). These conditions resulted in visible evidence of condensation and frost around and under the attic access hatch.

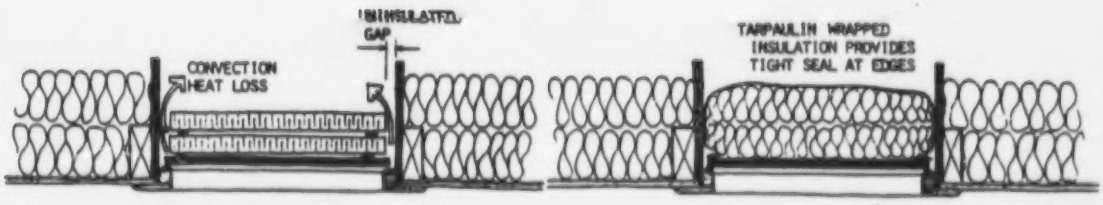


Fig. 4: Typical Insulated Attic Access Hatch.

Fig. 5: Attic Access Hatch with Good Air Seal and Insul.

The 1986 study [1] recommended that a tarpaulin-covered glass-fibre insulation batt be attached to the top of the hatch (Figure 5). The tight fitting insulation bag provides a good air seal to prevent convective losses around the insulation. The hatches are also weather-stripped to prevent moist air from migrating into the attic.

Because occupants rarely need to enter the attic, the access hatch can be located in the gable ends of the roof. This eliminates the need to penetrate ceilings and cuts-off the major source of air migration into the attic. RHAP recommends this method for most new houses.

2.1.5 Heating Duct into Crawl Space

Crawl spaces must be equipped with grilles to vent moisture escaping from the ground. However, occupants often close the grilles during the winter to increase the floor temperature. The grilles are then often left closed during the spring and summer, and moisture remains trapped.

In new houses, forced-air furnaces blow warm air into the crawl space from a single grille. This strategy not only warms the floor, but it dries the moist air in the crawl space. Eventually, water vapour that rises out of the crawl space will stabilize, but it will continue to add moisture into the house. For houses built over a particularly high water table, significant increases in water vapour can be expected.

Much of the rising dampness from the crawl space can be suppressed by the installation of a ground moisture barrier. However, if excessive amounts of ground water are present, the moisture barrier may trap enough water to turn the ground into mud. In those cases, the RHAP

housing officers recommended sealing the hot air grille into the crawl space, adding crawl space ventilation, and insulating the floor joists.

2.2 Milestones

DATE	TASK
1988	
September 28	- Begin investigation
November 7	- Field visit #1 - Inspect houses in Gift Lake - Set up hygrothermographs in four houses
December 9	- **Complete Phase I: Field Investigation**
1989	
February 15-16	- Field visit #2 - Install make-up air unit (MUA), Prototype #1 in House "B" - Cut holes for existing exhaust hood in kitchen - Modify furnace in House "A" - Cut exhaust hole in the ceiling
May 10	- Field visit #3 - Install MUA, Prototype #2 in House "B" - Inspect and modify House "C" in Wabasca
September 21	- Field visit #4 - Install MUA, Prototype #3 in the House "B"
1990	
January 17	- Increase fan speed and set temperature higher in the MUA unit #3 in House "B"
April 17	- **Complete Phase II: Retrofitting**
June 8	- Field visit #5 - Disconnect make-up air unit in the House "B" - Reclaim all hygrothermographs
June 30	- **Complete Phase III: Analysis**
September 20	- Submit final report.

3.0 MOISTURE GENERATION

Humidity is introduced into the average home from a wide range of sources. Some of these are as simple as washing floors or dishes and some are unexpected, such as plant transpiration and evaporation from potting soil. Generally, however, the sources are broken into two groups, natural and residential. Although somewhat arbitrary, they help to understand the problem of residential humidity.

3.1 Natural Sources

One of the major sources of moisture in some northern homes is the dirt floored crawl space. Moisture migrating up from the soil is prevented from escaping to the outside air because the residents often close the ventilation vents to maintain higher floor temperatures; consequently, the moist air moves up into the house. This situation is aggravated by poor drainage and improper grading. Other natural sources include leaky windows, improperly installed gutters or rainwater leaders, and melt-water from snow blown into an attic through various soffits or gable vents. All of these problems must be addressed before one can implement a humidity control program.

3.2 Residential Sources

By far the largest source of residential moisture is the lifestyle of the residents themselves. Natural expiration from the human biological process, cooking and washing activities, and even dogs and plants all put moisture into the air. This process is accelerated in many rural, northern homes where unique lifestyles and environmental conditions contribute their own additional moisture-load to homes. These contributors include: large families (up to 9 individuals); hanging clothes to dry indoors; dressing and storing wild game; storing wet firewood inside; a boiling-based cooking regime; and storing open water tanks inside to compensate for poor water supply and waste disposal problems. These all contribute to extreme and almost insurmountable humidity conditions. For a typical family, moisture generation can easily approach, or exceed, the scenario outlined in the following chart [11]:

Moisture Generation For a Typical Family

	Typical House "A" L/day	Typical House "B" L/day
Metabolic processes:		
2 adults, 2 children, 1 dog	5.5	
2 adults, 7 children, 1 dog		11.0
Cooking and washing	2.5	5.0
Crawl space under house	2.0	4.0
Miscellaneous (house plants, firewood drying, etc.)	0.5	0.5
Total Moisture Generation in L/day	10.5	20.5

This means that moisture is being generated at an average rate of 0.5 litres per hour. Naturally, the rate will vary throughout the day and from home to home. However, it clearly indicates the scale of moisture removal that must be undertaken in the study units. Specific calculations were made for each home studied in this project and are reported in sections 5.3, 5.4 and 5.5.

Condensation damage ranges from stains and growth of molds, to the deterioration of the building envelope, but simply devising an envelope to prevent interstitial condensation is inadequate. Window condensation and indoor air quality issues must also be considered.

3.3 Relative Humidity and Condensation

3.3.1 Condensation Design Temperature

Typical winter temperatures in Gift Lake do not often fall below -30°C [12,13]. The coldest periods occur in the early morning, when most moisture producing activities, such as cooking, bathing and washing, do not normally occur. In Gift Lake the reference design temperature for mitigating condensation is -20°C.

3.3.2 Maximum Relative Humidity Levels

Visible condensation is an indication of high moisture content [14] and forms when moist air meets any surface that has been cooled to the air's dew point temperature. Windows usually have the lowest temperatures because of their low thermal resistance. The solution to window condensation is to maintain the glass temperature above the dew point.

Table 1 below lists some recommended relative humidity levels which will prevent condensation on typical double-glazed windows.

TABLE 1: Recommended % Relative Humidity to Minimize Condensation on Double Glazed Windows.*

Outdoor Temp. °C	Alta. Energy	DBR NRC	Manit. Hydro	Illinois Energy	EM&R Enersave	CMHC	Average
-18 to -23	27	27	33	27	25	25	28
-23 to -29	23	23	27	23	20	20	23

* Sources [15,16,17,18,19,20]

For homes in this study, the indoor relative humidity should be maintained at 30%-35% during the winter [21]. Temperatures that fall below -23°C for short periods will cause some condensation on double glazed windows, but the primary concern is to prevent condensation damage to the building enclosure. Since walls, roofs and floors are more thermally efficient than double-glazed windows, an interior environment with up to 40% relative humidity is within tolerable limits.

4.0 MOISTURE REMOVAL

4.1 Methods to Reduce Indoor Relative Humidity

There are three ways to reduce high levels of humidity in a house: reduction of moisture generation, dehumidification, and ventilation.

4.1.1 Reduced Moisture Generation

One response to high relative humidity levels is to attack the problem at the moisture generation source. Some conditions such as poor site drainage, improved rainwater leaders or moisture barriers in crawl spaces can be corrected. However, the lifestyle sources listed in 3.2 are more difficult to influence. While such activities as drying clothes and storing wood in the home can be modified, it is impossible or unreasonable to suggest more personal interventions such as occupancy numbers or cooking (boiling) habits. Consequently, moisture modification strategies must focus on removal rather than prevention.

4.1.2 Dehumidification

An obvious moisture removal strategy is chemical or mechanical dehumidification. Unfortunately these devices are costly, they consume electricity and are not always dependable, particularly portable units. Furthermore, mechanical dehumidification does not reduce the relative humidity to below 50%, which is the level necessary to prevent condensation when outdoor air temperatures are -23°C [22].

4.1.3 Ventilation

The third method of lowering indoor relative humidity is to mix the humid indoor air with cold, but dry, outdoor air. When cold air comes into the house, the indoor relative humidity is lowered because the cold air does not hold as much moisture as the warm air. For example, air at -5°C can only hold one sixth (0.003 kg water/kg dry air) as much water as air at 23°C (0.018 kg water/kg dry air) [23]. Furthermore, when cold air is brought into a home equal amounts of moist indoor air are exhausted outside thus doubling the benefits.

4.2 Ventilation

4.2.1 Ventilation Rates

Many authorities [24,25] consider ventilation to be the only practical method of lowering indoor relative humidity levels during the winter in northern climes. The rate of moisture removal through ventilation can be very effective. The ASHRAE method for calculating the rate of moisture removal for a home is as follows [27]:

$$Wr = Q \times C_5 \times (W_i - W_o) \times C_4$$

where:
- Wr = rate of moisture removal (kg/hr)
- Q = ventilation rate (L/s)
- C_5 = standard air density (1.2041 kg/m^3)
- W_i = moisture content of inside air (kg/kg dry air)
- W_o = moisture content of outside air (kg/kg dry air)
- C_4 = constant 3.6 (sec x m^3)/(hr x L)

For example, the ventilation rate can be calculated if we know the house volume and the rate of air change per hour (ach). For the ½ ach which is typical to many northern homes,

$$Q = \frac{\text{house volume}}{3.6} \times \text{air change}$$

$$= \frac{87\ m^2 \times 2.44\ m}{3.6} \times 0.5$$

$$= 30\ L/s$$

When the conditions inside a house are 52% relative humidity at 22°C and outdoor conditions are -1.6°C at 90% RH, the psychrometric chart [23] gives moisture contents of 0.0085 and 0.003 (kg/kg dry air) for indoor and outdoor air respectively. Moisture removal in the house is calculated as follows:

$$Wr = Q \times C_5 \times (W_i - W_o) \times 3.6$$
$$= 30 \times 1.2041 \times (0.0085 - 0.003) \times 3.6$$
$$= 0.72\ kg/hr$$

Under these conditions, a ventilation rate of ½ air change per hour removes 0.72 kg/hr of moisture. As noted in Section 3, in the average home, moisture is generated at a rate of 0.42 kg/hr or 10.5 L/day; thus under the described conditions, the ventilation rate is sufficient to prevent condensation problems in house "A".

In house "B", the same ventilation rate of ½ air change per hour, with relative humidity of 57% at 24°C (moisture content is 0.01 kg/kg), moisture removal is calculated as:

$$Wr = Q \times C \times (W_i - W_o) \times 3.6$$
$$= 30 \times 1.2041 \times (0.01 - 0.003) \times 3.6$$
$$= 0.91 \text{ kg/hr}$$

The amount of moisture removed from House "B" (20.5 L/day) should be higher than House "A" because the original air is more humid.

These calculations can only be estimates because natural air leakage cannot be calculated, nor can the frequency of opening outside doors. Also occupant metabolism rates and living habits vary. Nevertheless, the above figures indicate an acceptable approximation for the average residence. Unfortunately, the moisture removal rate through ventilation is not constant; as the house becomes drier, the moisture removal rate decreases. To remove the same quantity of moisture when the relative humidity is lower requires a higher ventilation rate.

The relationship between moisture and total ventilation [27] is illustrated in figure 6. This graph illustrates the relationship between moisture generation and air change rate, along with the resulting indoor relative humidity level for an outdoor temperature at -18°C and 100% relative humidity. According to the chart, House "B", which generates 20.5 L/day of moisture, should require a ventilation rate of approximately 45 L/s to maintain a 30% indoor relative humidity. Obviously the ventilation rate will vary when the exterior temperature and relative humidity changes.

The experiment showed that a ventilation rate of 30 L/s for House "B" only reduced the relative humidity to 47%, which correlates very well with the chart in Figure 6.

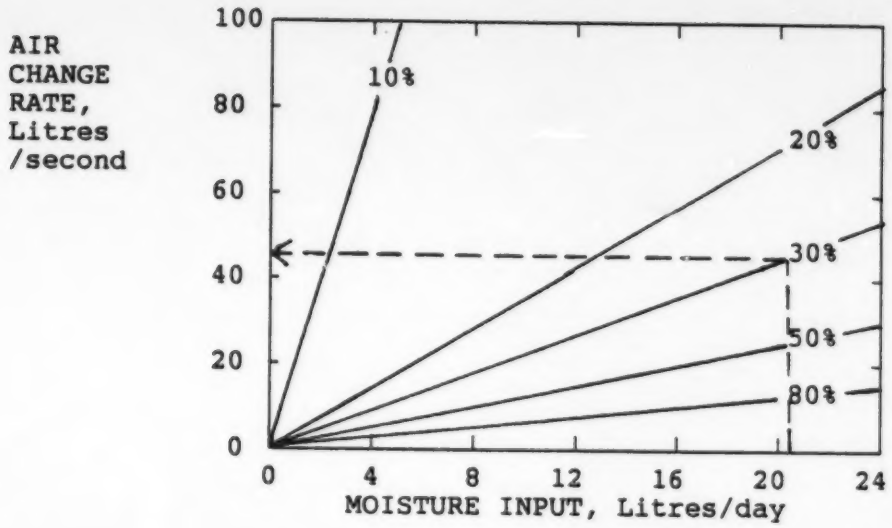


Fig. 6: Indoor Humidity Balance At 18°C and 100% R.H. Outdoor

The ventilation required to remove the moist air and effect the necessary air change can be achieved through either passive air movement that depends primarily upon the stack effect (the tendency for warm air to rise), or mechanical means (usually a fan). The merits of each method are outlined below.

4.2.2 Passive Ventilation and Stack Effect

The natural buoyancy of heated air causes natural ventilation. As air heats up, it expands, becomes lighter and rises. For example, a hole in the ceiling would allow warm moist air into the attic, but the moisture in the air would then condense in the attic. A better solution would be a duct extending from under the ceiling through to the top of the roof. Warm moisture-laden air rising naturally through the vent would help to dry out the house. A wind turbine such as the popular "whirlybird" ventilators, could be positioned on the exhaust vent above the roof to assist in air removal.

The stack effect causes higher air pressure at the top of the house, with lower air pressure occurring at floor level. Across the building enclosure, at mid-height is a neutral pressure plane (NPP) with no differential air pressure (Figure 7)[28] relative to the exterior. The air pressure difference across the exterior wall will result in negative air pressure that will allow air infiltration at grade

level. At the same time it will result in exfiltration at the ceiling level (Figure 8). Any opening in the ceiling will draw air out of the house.

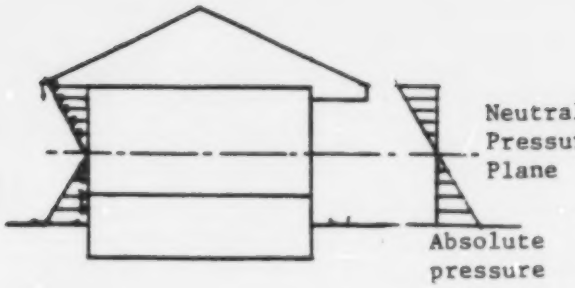


Fig. 7: Air Pressure on the Walls

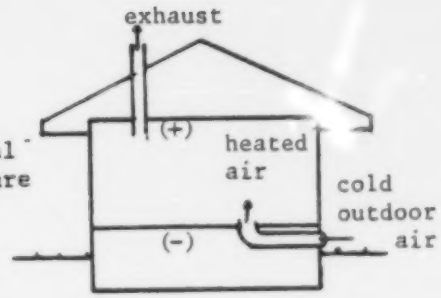


Fig. 8: Stack Effect Causing Ventilation

Shaw and Kim [29] described the potential for passive ventilation systems based on their own tests. With a vent opening of only 127 mm in diameter, a measured air change rate between 0.26 to 0.42 air changes per hour, was observed depending on the location and configuration of openings. The airflow through a 100 mm diameter vent averaged 7.5 L/s. While this work focussed on two-storey homes, the data suggests that comparable findings are to be expected from single-storey residences.

The major factor affecting rates of air change is the temperature difference between interior and exterior air. The bigger the difference, the greater the stack effect and passive ventilation rate. Unless the wind speed exceeds 30 km/hr, it does not significantly affect the passive ventilation rate during the winter. However, during mild weather, wind influence is more noticeable because of the decreased stack effect.

In the Shaw and Kim test homes, exhaust vents penetrated the ceiling and attic and exited vertically through the roof. For the most part, the air change rate and exhaust stack flow remained unchanged regardless of the exhaust vent inlet location. If the vent was extended to the floor or even to the basement, the airflow rate remained the same as when using a short duct at the ceiling. It was this observation that suggested the findings had direct application to single-storey homes. Similarly, the location of the air supply vent did not affect the ventilation rate.

By doubling the openings there was only a slight increase in passive ventilation. Rather than increasing the rate of ventilation, the stack effect equally redistributes the air to all vent openings. The slight increase in ventilation rates are caused by decreases in frictional losses through the ducts.

It is possible to utilize passive ventilation to reduce indoor humidity; determining whether the rate of ventilation is a viable means to sufficiently reduce indoor relative humidity and prevent condensation is one objective of this study.

The advantages of static ventilators are:

- no external power required
- simple installation, lower cost
- no moving parts that require maintenance
- quiet operation
- no occupant participation required
- the rate of ventilation is directly proportional to temperature difference

The disadvantages of static ventilators are:

- ventilation rates are affected by air pressure changes resulting from wind, opening doors, and furnace or fireplace operations
- relatively low ventilation rates may not be sufficient to reduce humidity to the required level
- control (on/off regulation) cannot be easily accomplished
- efficient operation requires large ducts with minimal bends
- high potential for snow, down-drafts, rain and dust to enter through roof ventilators
- susceptibility to formation of condensation and frost in ducts
- constant heat loss through uncontrolled air leakage
- incoming cold air may cause discomfort to occupants

Strategies to mitigate some disadvantages of static ventilators are:

- install wind and snow deflector caps on top of ventilating ducts
- install automatic dampers activated by a dehumidistat to reduce excessive ventilation rate and heat loss
- provide a fresh air inlet to mix with warm indoor air.

4.2.3 Mechanical Ventilation

Mechanical ventilation commonly uses electrically powered fans to draw air into or exhaust air from the house. Typically, exhaust fans are located in kitchens and bathrooms where they can exhaust moisture laden air before the water vapours can circulate throughout the house. Mechanical ventilation is more dependable and offers better control than natural, passive ventilation.

(a) Air Management

Proper air management involves both ventilation and distribution. When air is exhausted from the house, replacement air must be brought in. Also, supply air vents must be strategically located for effective distribution of dry air throughout the home.

Exhaust-only ventilation systems, such as bathroom or kitchen exhaust fans, pull outside air into the house through openings, cracks and joints in an inadequately sealed building enclosure. The exhaust-only system can create sufficient suction to cause backdrafting in chimney flues [30,31,32]. Backdrafting is dangerous because, when stove or fireplace exhaust gases are drawn down the chimney and into the home, asphyxiation can occur. Between 1973 and 1983, 150 people died in Canada due to carbon monoxide (CO) induced asphyxia from chimney backdrafting [33]. Flue spillage was found to occur in 10% of 800 Canadian gas-heated houses surveyed in 1987 [34]. Therefore ventilation systems should be balanced by openings that will equalize pressure across the building envelope. A balanced ventilation system consists of a fresh air inlet that draws air into the house, and an exhaust fan that exhausts an equal amount of indoor air to the outside (Figure 9).

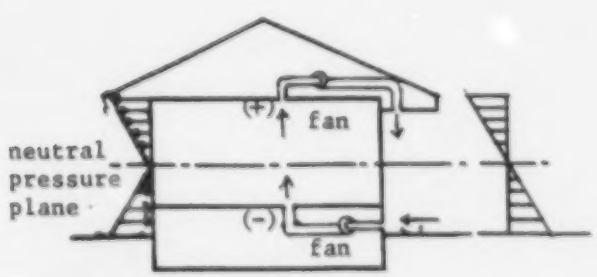


Fig. 9: Balanced Air Pressure System

(b) Vent Locations

To be effective, supply and exhaust vents must be strategically located relative to each other. To avoid short-circuiting, exhaust vents should not be located next to supply vents.

While natural venting requires ducts to be large, with minimal bends, duct orientation and bends do not affect mechanical ventilation systems in the same way. Therefore, mechanically ventilated ducts can be installed above the ceiling, run horizontally through the attic, and exit through the soffit vents.

The primary advantages of powered mechanical ventilation systems are:

- dependability
- constant ventilation rates
- ease of control
- the ability to use smaller ducts
- greater freedom of location

The disadvantages are:

- more expensive than static ventilating systems
- electrical installation required
- electrical power dependency
- regular maintenance is required to minimize breakdowns
- potentially noisy
- must be sheltered from severe weather, dust, grease, smoke, etc.

Strategies to mitigate the disadvantages of mechanical ventilation include:

- specify ventilation fans with low noise rating
- install fans with proper isolation mounts
- install noisy fans in isolated areas, such as attic and crawl space
- avoid using the highest fan speed
- filter supply-air upstream from the fan
- locate exhaust fans away from major areas of household dust and grease

(c) Pressure Systems

All active ventilation systems fall into three basic categories: negative pressure (exhaust driven), positive

pressure (supply driven), and neutral pressure (double flow - supply and exhaust). Each ventilation system has advantages and disadvantages.

(i) Negative Pressure

Bathroom or kitchen fans, exhaust air from the house (See Figure 10), but negative pressure is created if outside air is not brought in to replace the exhausted air [35]. Typically, kitchen exhaust fans are mounted directly above the range. A regularly cleaned grease screen should be used to catch the cooking grease. The advantages of negative pressure systems are:

- moist air is exhausted near the source of generation
- fairly low cost due to simplicity and availability
- easy operation; ie. turn on fan when there is excess humidity
- fan is located in a less severe, indoor environment

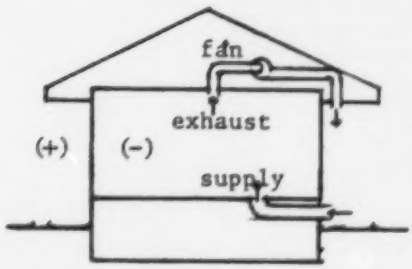


Figure 10: Mechanical Exhaust Creating Negative Pressure

The disadvantages are:

- may cause sufficient negative pressure to result in backdrafting of chimney gases
- cold air can be drawn through unregulated openings in building enclosure
- effective filtering of fresh incoming air is difficult
- exhaust fan operation can be hampered by grease, smoke, and other household pollutants
- the tempering of incoming air is difficult
- typical bathroom and kitchen exhaust fans are noisy
- frost may develop on supply ducts.
- excessive electrical consumption

Solutions to mitigate these disadvantages include:

- provide a fresh air inlet to balance negative pressure
- locate the air filter in the incoming plenum
- add a replaceable air filter to the typical insect screen and grille at the intake opening,
- preheat incoming air with a make-up air unit
- reduce fan operation and heat loss during periods of low indoor humidity by using a dehumidistat to control fan operation

(ii) Positive Pressure

Supply fans draw air into the house and distribute it through strategically located air registers to create positive pressure (See Figure 11) relative to outdoors. The resulting differential air pressure must be relieved; otherwise, the pressurized house could drive moist air into the wall and roof systems where condensation can damage the building enclosure.

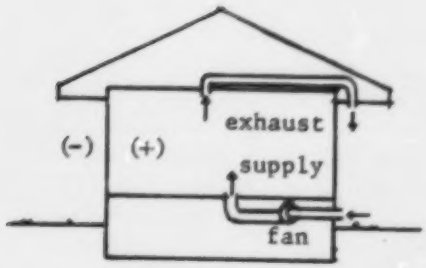


Figure 11: Make-up Air Unit - Positive Pressure

Although supply air can enter the house independently of the furnace, when the outdoor temperature is low the cold air brought in can be noticeable and uncomfortable. This may tempt occupants to block off the cold air supply. Alternatively, the incoming fresh air can be heated by an in-duct resistance heater.

The advantages of a positive pressure ventilation system are as follows:

- the fan is free from indoor pollutants, such as grease, dust, etc.
- outdoor air supply is directed to strategic locations throughout the house
- the system is simple to operate
- a fresh air duct can be connected to the return air duct of the furnace
- there is no backdrafting
- fresh air registers can be located in high moisture-producing areas, such as the kitchen and bathroom, to help push out moisture laden air

The disadvantages are:

- high pressures may cause interstitial condensation in building enclosure
- supply fan may be subjected to outdoor dirt, sand, snow, etc., brought in with the supply air
- supply fan can be subjected to cold outdoor temperatures
- cold air supply can cause discomfort for occupants
- excessive electrical consumption

Solutions that can mitigate these disadvantages are:

- control the airflow rate to avoid high air pressures inside the house
- balance positive pressure by providing air outlets, such as bathroom and kitchen exhaust ducts
- provide an in-duct heater to preheat incoming air and locate the fan downstream of the heating element
- in addition to providing the typical insect screen and grille at the intake opening, add a replaceable air filter upstream of the heating element and fan
- install a dehumidistat controller to reduce fan operation and heat loss during periods of low indoor humidity

(iii) Neutral Pressure System

Neutral pressure systems involve two synchronized fans: one for fresh air supply and one for exhaust (See Figure 12). Of the three methods this is the most complicated and expensive. The other two systems can achieve the same results by using only one fan, as long as the fan is balanced with an air inlet or outlet.

In addition to balanced pressures, the neutral pressure ventilation system has the same advantages as the negative and positive pressure systems:

The disadvantages are:

- twice the cost to supply and install two fans
- supply fans have the same disadvantages as the positive ventilation system
- exhaust fans have the same disadvantages as the negative pressure system
- twice the electrical consumption of the supply or exhaust system

Solutions to mitigate these disadvantages are similar to those cited for both the positive and negative pressure systems.

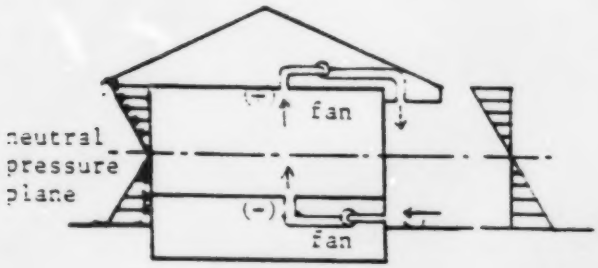


Fig. 12: Balanced Supply and Exhaust System

Of the three powered mechanical ventilation systems, the positive pressure system is the most reasonable and effective. The negative air pressure system cannot be considered due to chimney backdrafting hazards. The neutral pressure system is too complicated and expensive. Because of these facts, the field trials investigated various options exploring the positive pressure approach to ventilation of high indoor humidities.

5.0 FIELD TRIALS OF THREE SYSTEMS

5.1 Selection of Houses

On November 7, 1988, an initial site-visit was conducted to several houses north and northwest of Slave Lake, in the area of Gift Lake. The weather during the visit was sunny with light snow covering the ground, light winds and an air temperature of -1.6°C. The examination provided information about the degree of condensation damage, the level of humidity and the occupants' characteristics. A number of the houses examined were not used for this investigation because they were in fairly good condition. Other houses were particularly prone to condensation damage but their lifestyle habits were so unique that no reasonable amount of retrofitting would improve their situation. In discussions with the housing officers, we decided to focus on those houses which were most representative of the norm and for which successful prototype systems might have the broadest application.

5.2 General Field Techniques

Information on house design, construction details, materials, and workmanship was obtained from housing officers, local builders, and Settlement officials. Interviews with the inhabitants revealed the number of occupants, lifestyles, and the frequency and extent of visible condensation.

Interior and exterior temperatures and relative humidity levels were recorded over the 1988 - 1989 winter period and after the modifications, to quantify the impact of the various remedial measures. In response to feedback from the occupants and housing officers, adjustments to the modifications were made to refine the level of ventilation.

During the entire period of this study, communication was maintained with RHAP housing officers and the occupants of the retrofitted houses. In addition the housing officers changed the hygrothermograph charts and obtained weather data

On June 8, 1990, a final site visit was undertaken to examine the retrofit devices and to obtain final feedback from the occupants and housing officers.

5.3 House "A", Gift Lake:
(Increase Furnace Fresh-Air Intake)

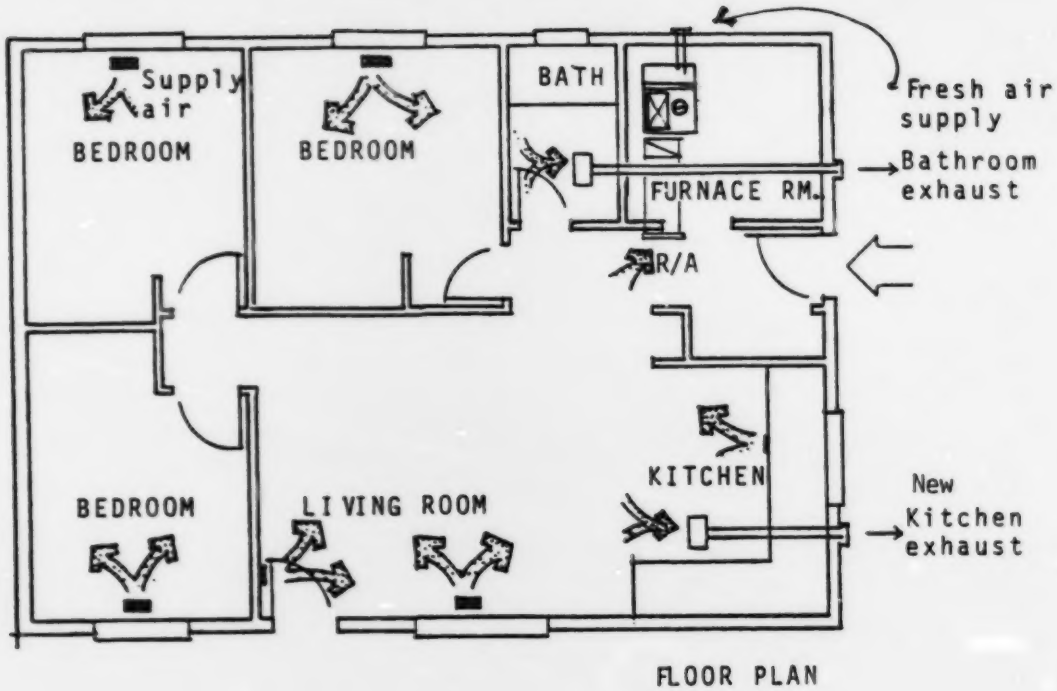
5.3.1 Site Description and Problem Identification

House "A", a 87 m² (936 sq.ft.) bungalow (see figure 13), was built four years ago and is presently occupied by two adults, two children and a dog. Initially there was no water supply or septic disposal system, but these were installed during the monitoring period. The house is surrounded by essentially rugged terrain, with some evergreen trees scattered throughout the area. A gravel and dirt road leads to a moderate sized gravel and dirt parking area. With even a moderate amount of precipitation, the surrounding site becomes wet and very muddy. A small boardwalk leads from the parking area to the front door.

Upon entering the house, there was a noticeable odour and the air was rather humid. An uncovered 45 gallon cistern was located in the entry coat-closet. There were no doors on the closet, or on the short entry-corridor. The house had a very high relative humidity ranging from 45% to 60% at 22°C; while the crawl space had a relative humidity in excess of 55% at 19°C. The temperature throughout the rest of the house was fairly uniform but the occupants indicated the bedrooms were somewhat cooler during very cold weather. Noticeably missing was a kitchen exhaust fan.

Water stains and condensation damage were evident on most inside window sills, on the wall below the sills and on the ceiling tiles in the living room and kitchen. The occupants reported that condensation on the windows sometimes turned to frost during the winter. The bedroom floors, particularly in the outside corners, also developed frost at times. The living room exterior door, which is rarely used, was covered with a sheet of polyethylene to stop the cold drafts.

A hygrothermograph was positioned on top of the refrigerator to record indoor temperature and relative humidity.



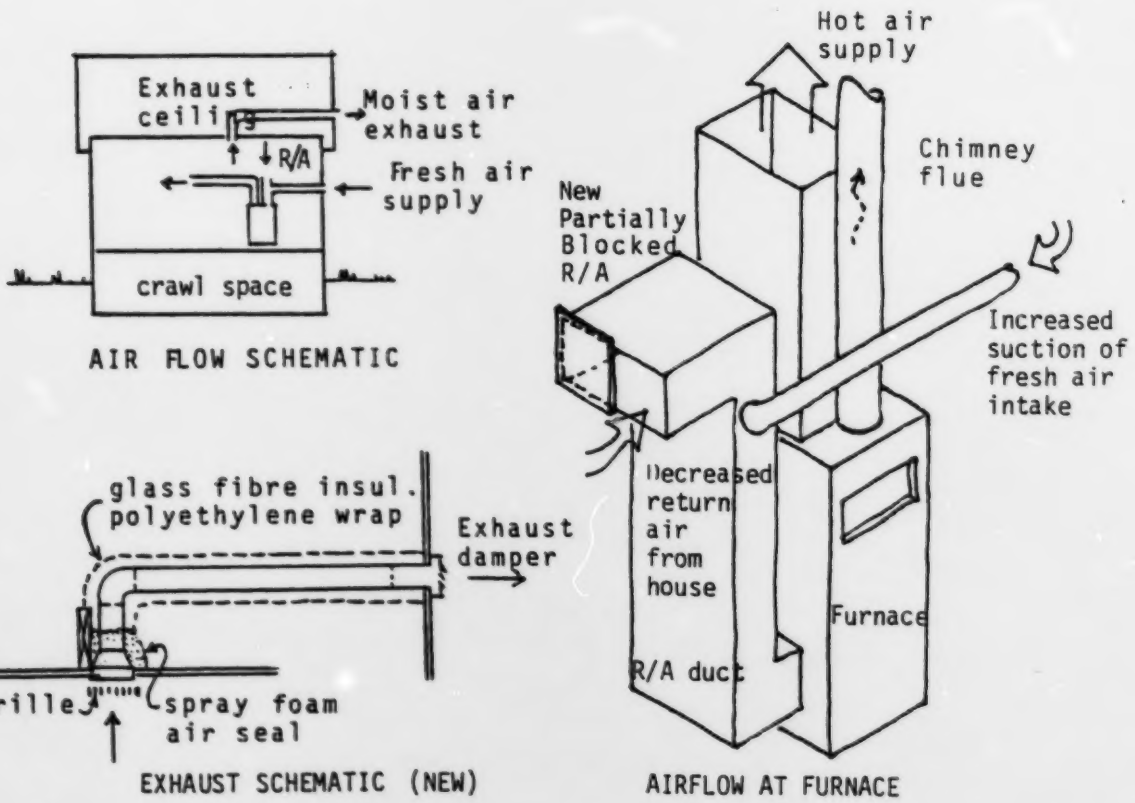


Fig. 13: Increase Furnace Fresh Air Intake and Install Kitchen Exhaust, House "A"

5.3.2 Mitigation

(a) Existing System Description

House "A" utilized a 125 mm fresh air supply duct to bring dry outdoor air into the furnace and create a positive pressure ventilation system as the intended method of reducing humidity (See Figure 13). In theory, this approach has the advantage of directly relating furnace operation to ventilation (humidity control) requirements. The colder the weather (which requires frequent furnace operation) the greater the need to lower the indoor relative humidity.

(b) Retrofit Installation

The house ventilation system was modified by the installation of one 100 mm diameter (4") ceiling exhaust duct. Originally a second exhaust duct was planned, but proved unnecessary because the house already contained many leakage paths.

The return air grille was partially blocked to reduce the volume of interior air returning to the furnace. To compensate, the furnace had to draw more air from the fresh air intake. At 50% blockage of the return air grille, fresh air intake increased from 28 L/s to 60 L/s, or 48 L/s when combustion air was deducted, which approximates the calculated requirement of 40 L/s.

One concern is that cold air supplied directly to a furnace may cause sufficient thermal shock to develop cracks in the heat exchanger [36]. Furthermore, condensation may develop when cold air and warm moist air meet in the return air duct. However, in this case it was unlikely that thermal shock and condensation would occur as the furnace operated at 710 L/s and the fresh air intake was only 60 L/s or 8% of the flow rate.

The condensation which may develop when cold fresh air is mixed in the warm, humid return air duct can cause corrosion in the ducts and furnace. Fortunately, this only occurs when the house air is very humid. As outside air enters the house, it forces humid air out and the return air becomes increasingly dry. Consequently, condensation mist will not form as readily as the indoor relative humidity decreases.

5.3.3 Observations

In February 1990, after almost one year of successful operation, the residents of House "A" reported a decrease in visible condensation. They also indicated the house was colder. The hygrothermograph charts indicated an average indoor temperature of between 25°C to 28°C. For the period starting January 27, 1990, the house temperature dropped to 23°C, which corresponded with a particularly cold period when outdoor temperatures plunged to almost -37°C. During the coldest period before the modifications in 1989 (-35.3°C on January 9) the house maintained a steady 25°C.

House "A" is equipped with an Olsen propane furnace, rated at 72,000 Btu input, and 54,720 Btu output. The furnace is only 6 years old, but a plugged air filter and lack of upkeep have affected its efficiency. Consequently, the furnace did not have sufficient heating capacity for exceptionally cold periods. Furthermore, the retrofit measure which partially blocked the return air grilles, may have caused inadequate heat distribution resulting in a small reduction in air delivery to each room. The increased ventilation to control humidity also increased building heat loss.

Unfortunately, the hygrothermograph installed in House "A" was tampered with during the monitoring period. Thus improvements to indoor relative humidity were not accurately recorded. However, based on instantaneous RH readings, observations of the housing officers, occupants, and other direct observations, it was estimated that relative humidity was lowered from an average of 50% to almost 40%.

5.3.4 Findings

Modifications to House "A" consisted of reducing the area of the return air intake vent by 50%, and providing an exhaust vent in the ceiling. Unfortunately, reducing the size of the return air intake will also reduce the efficiency of the air circulation system. The reduced airflow may be insufficient to heat the house during extremely cold weather.

The fresh air intake in typical RHAP houses is only 125 mm (5") diameter. Increasing the fresh air intake is possible by increasing the duct to 150 mm (6") diameter, which is a 40% enlargement of the cross-section area of the duct. With the larger diameter

fresh air intake duct, it may not be necessary to block as much of the return air duct to achieve the same result.

Because the furnace operation is not continuous, it cannot be depended on to supply fresh air into the house. While there is some correlation between moisture removal and furnace operation, it is not dependable. If the furnace fan was operated continuously, the indoor relative humidity could be sufficiently lowered. However the extra electrical consumption, the noise, the draft, and wear and tear on the furnace appear to override the potential advantages.

5.4 House "B", Gift Lake: (Make-up Air Unit)

5.4.1 Site Description and Problem Identification

This one-year-old, 87 m² (936 sq.ft.), three bedroom house (see Figure 14) was occupied by 9 people and a dog. It exhibited severe condensation. An entry porch was attached to the predominantly-used rear door. Water service and sewage disposal were installed during construction and there were no open containers of water. A bathroom fan was occasionally used by the occupants.

Despite the mild -1.6°C outdoor temperature, condensation on most of the windows indicated humidity problems. Most window sills were wet and stained. A reading of 57% relative humidity at 24°C was recorded.

This house contained a high (1200 mm) crawl space. A ship's ladder was permanently installed to access the crawl space from the interior of the house and dry goods were stored in one corner. The ground was not covered by a moisture barrier. The crawl space temperature was warmed to 17°C by a single heating vent. Relative humidity in the crawl space approached saturation. The local contractor reported that a nearby drainage swale had previously channeled ground water under the house. He improved conditions in the crawl space by diverting water from the house, but moisture levels in the house were not significantly reduced.

A hygrothermograph was placed on top of the kitchen cabinet to record any changes to the relative humidity levels in this house.

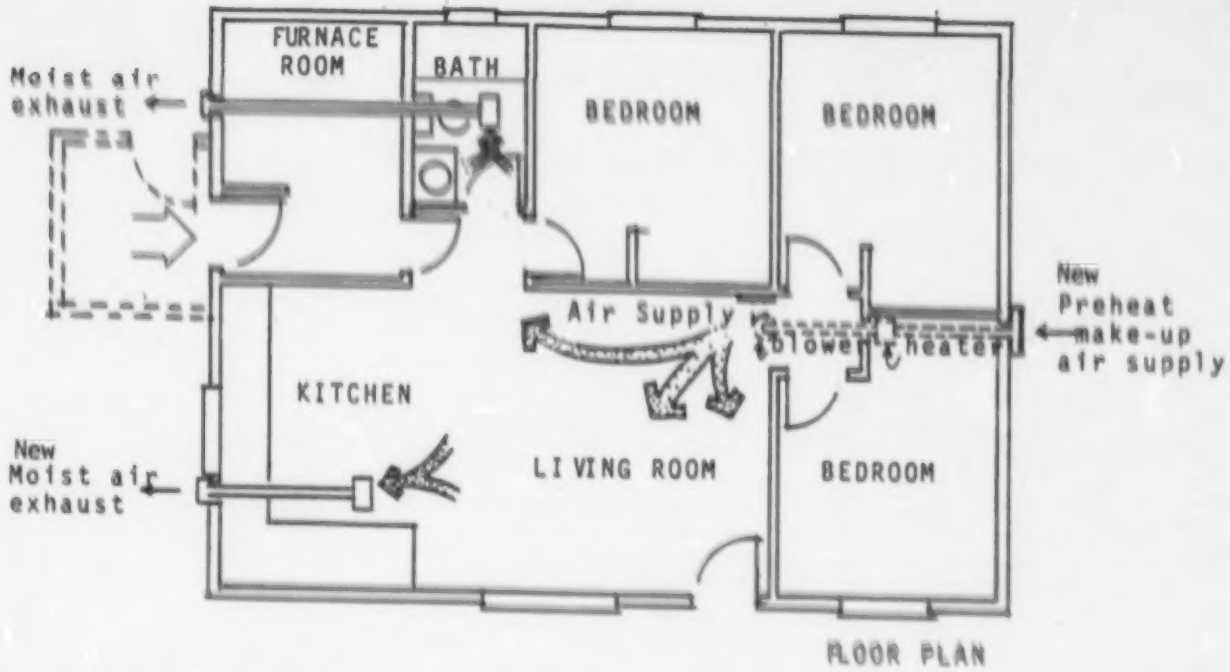
5.4.2 Mitigation

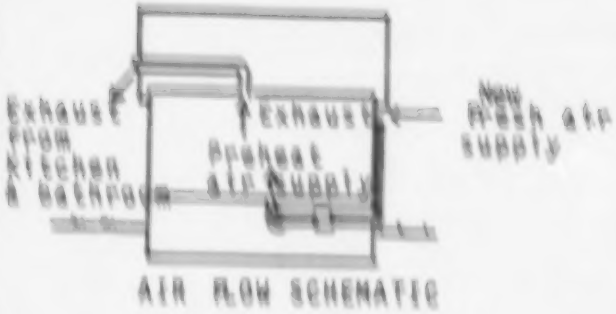
(a) Existing System Description

A typical forced air furnace was installed in House "B", along with the requisite 125 mm fresh air supply duct. Similar to House "A", there was a bathroom vent but no kitchen exhaust fan.

(b) Retrofit System Description

The high humidity in House "B" was attributed to the number of residents and constant entry to the damp crawl space. Consequently, a solution offering greater response, sophistication and control than could be provided by the furnace as demonstrated in House "A" was





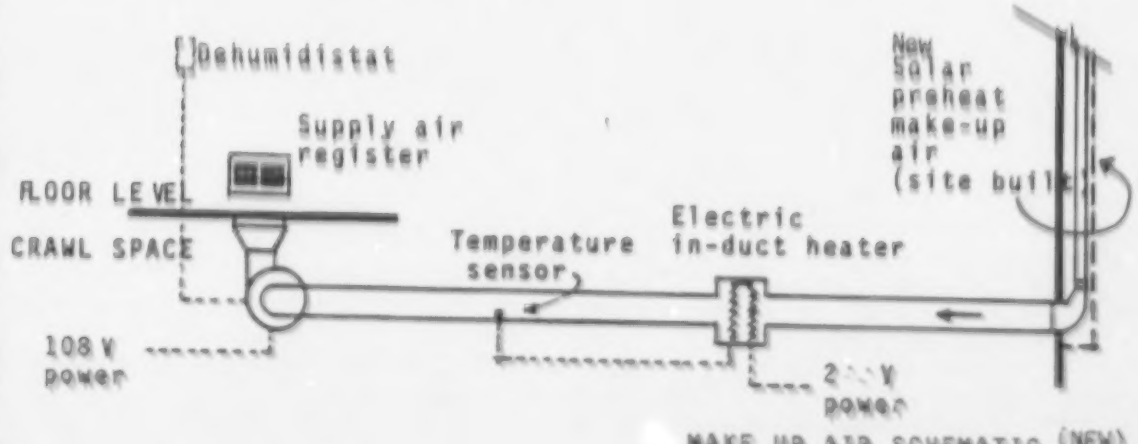


Fig. 14: Make-up Air Unit, House B

required. In this case, a mechanically-powered fresh-air supply system (make-up air unit) was proposed to reduce the level of indoor humidity and the resulting condensation damage (see Figure 14).

Fresh air was brought in through a supply fan controlled by a dehumidistat. To avoid occupant discomfort, an electric resistance in-duct heater preheated the air to approximately 18°C (65°F) before it was discharged into the house in a remote location away from the kitchen and bathroom.

In Gift Lake, the design snow load is 3.2 kPa, which is one of the heaviest in Alberta. This required that the intake grille be positioned fairly high above the ground. This provided the opportunity to incorporate a solar collector to preheat the make-up air. A simple site-built solar collector was mounted on a south-facing wall to capture some available solar heat (See Figure 15). The solar preheater, which extended the intake opening to the underside of the roof, represented a very modest additional cost.

A replaceable air filter was incorporated into the supply duct to prevent damage to the blower and fan, and to prevent dirt from entering the house.

Supplying air into a house without exhausting the same amount of air could force moist air into the building enclosure. Because the existing 75 mm (3") diameter exhaust duct in the bathroom was insufficient to discharge the expected volume of supply air, a hole was cut in the wall for the exhaust outlet, which was connected to the kitchen exhaust hood. The existing hood merely recirculated the air in the kitchen and did not even contain a charcoal filter. Installing this exhaust route fulfilled our exhaust requirement and facilitated the removal of the odour and grease laden cooking fumes. A one-way damper was installed to prevent backdrafting. When the make-up air unit is operating, the retrofit kitchen exhaust and the existing bathroom exhaust opening are sufficient to balance the house ventilation.

Three successive make-up air unit prototypes were installed in house "B". The following section describes the prototypes and their performance.

(c) Prototype Make-Up Air Units

(i) Prototype #1

The first prototype make-up air unit consisted of a store bought electric space heater. The heater was designed to maintain a consistent set-temperature, regardless of intake air temperature. A temperature sensing microprocessor controlled the power supplied to the ceramic heating element.

The space heater (Microfurnace) was installed in an air supply duct. Although the space heater contained its own fan, a downstream fan was added to ensure adequate airflow. This fan was controlled by a room dehumidistat. When the indoor relative humidity exceeded a preset level, the fan drew outdoor air across the space heater, where it was preheated before discharging into the house (See Figure 15).

Figure 15: Make-up Air Unit - Prototype #1

Tests indicated a supply airflow of approximately 37 L/s, which was less than the calculated requirement of 50 L/s. It was concluded that the Microfurnace with its large ceramic heating element installed in the 200 mm

(8") diameter duct had restricted the airflow. The fan was also considered to be too loud.

Controlling the temperature of the heater was a more serious problem. The built-in temperature controller located in the Microfurnace senses the air entering the heater. The heater is designed for indoor use and is expected to sense incoming room air. If the heater always detects low outdoor temperatures, it will always operate at its highest setting, resulting in the overheating of the supply air and causing excessive power consumption.

(ii) Prototype #2.

Based on findings from the original unit, the fabrication of a duct with an in-line electric resistance heating element was commissioned. In addition, the fan was replaced with a centrifugal blower to increase the rate of airflow and to reduce fan noise. A flow switch was also installed to shut off the heater when airflow ceased in the duct. The flow switch was a back-up safety measure to prevent overheating (see Figure 16). A time lapse meter was installed to record operation of the blower.

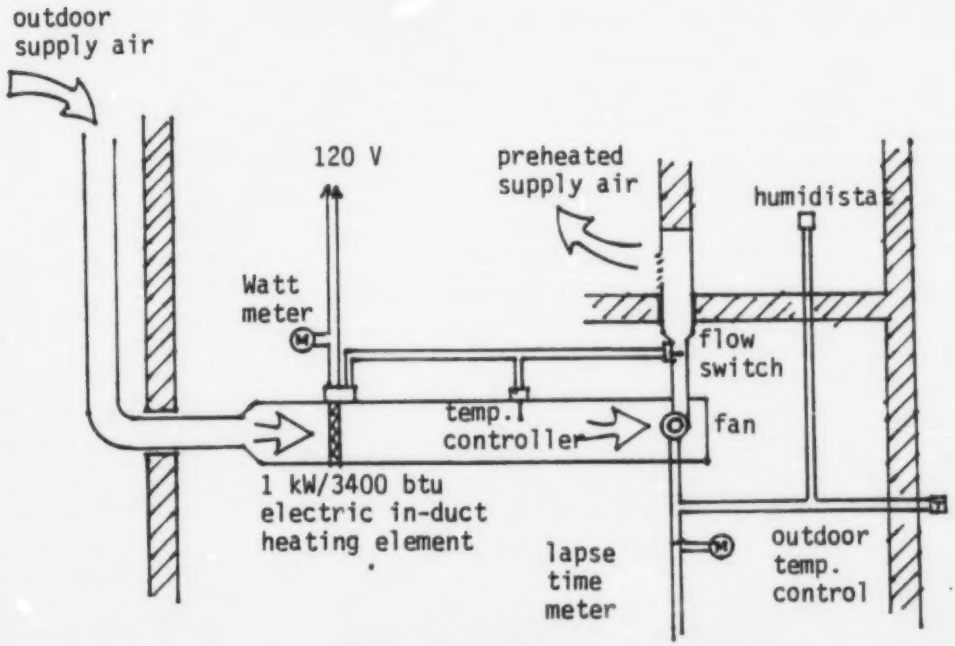


Figure 16: Schematic of Make-up Air Unit - Prototype #2.

While this prototype proved better than the previous unit, the new centrifugal blower was, unfortunately, noisier than the axial fan.

(iii) Prototype #3

During the design, fabrication and installation of the first two prototypes, efforts were made to locate a commercially available make-up air unit. To this end, several suppliers were contacted to locate a unit with the following features:

- an in-duct heater to raise outdoor air from -32°C to 18°C at a flow rate of 50 L/s that would only operate when the fan is operating
- a variable speed fan with a range of 30 - 75 L/s
- a control system capable of responding to input signals from an existing dehumidistat located in the house and an outside air temperature sensor

Dexon Canada Manufacturing Corporation of Calgary suggested modifying their sewage lift-station vent heaters to match these specifications. A compact make-up air unit was designed, assembled, and installed in House "B" on September 21, 1989. The operating temperature was set at 17°C. A schematic diagram of the make-up air unit is shown in Figure 17. The modified unit has the following features:

- an axial D.C. fan capable of producing up to 75 L/s airflow
- an electric heating element around the fan to control frost
- a 3.8 kW, 240 volt electric element for heating supply air
- adjustable supply air temperature
- unit activation whenever dehumidistat is set higher than 20% relative humidity
- thermostatically controlled disconnection of power to the unit whenever the outdoor temperature is higher than 10°C
- high temperature cutoff
- modulated infinitely heating element to meet heating demand

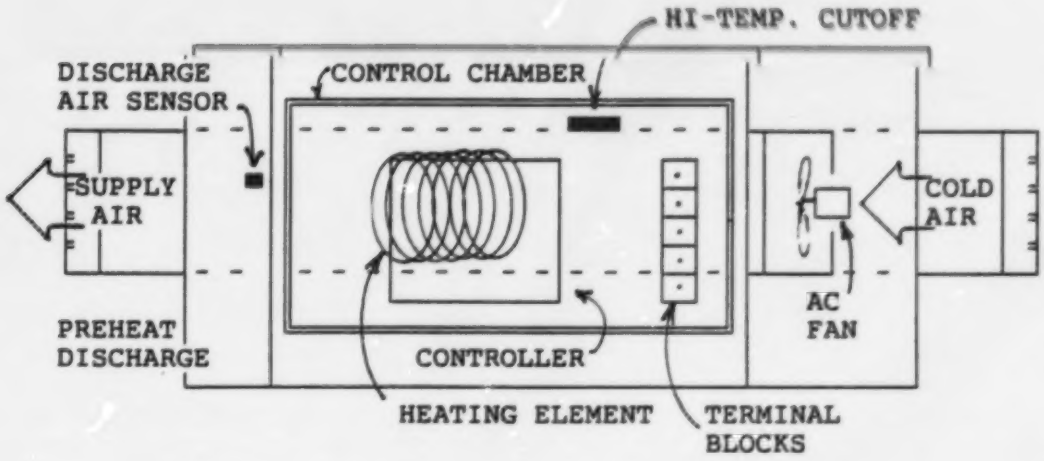


Fig. 17: Schematic of the Make-up Air Unit, Prototype #3 (By Dexon Canada Manufacturing Corporation)

Tests conducted after installation of Prototype make-up air unit #3 established the following performance standards:

- airflow rate at 50 L/s (no static pressure), but capable of increasing to 75 L/s
- noise measured at only 37 dBA at one metre from the discharge grille.

5.4.3 Observations

(a) Preliminary Results and Occupant Perception

In mid-January, the occupants reported the make-up air unit did not seem to be operating. A Housing Officer with the Rural Home Assistance Program examined House "B" on February 1, 1990. He changed the hygrothermograph charts and undertook a diagnostic check, which indicated that the #3 prototype make-up air unit was indeed operating as intended.

As indicated in Table 2, the hygrothermograph charts for January show that indoor relative humidity was gradually decreasing.

TABLE 2: JANUARY INDOOR TEMPERATURES AND RELATIVE HUMIDITIES (House "B")				
DATE	AVERAGE INDOOR TEMPERATURE	LOW R.H.	HIGH R.H.	AVERAGE R.H.
Jan/89	24°C	55%	65%	60%
Jan/90	25°C	45%	55%	47%
Jan/90*	25°C	38%	40%	40%

* after increasing fan speed.

The problem as perceived by the occupants must be considered within the context of prevailing weather conditions. When the outdoor temperature is approximately -5°C, condensation will still occur on a double-glazed window at 47% relative humidity. At 25% relative humidity, condensation will not form on the window until outdoor air temperatures reach between -23°C to -29°C. The mean monthly temperature in November 1989 was -5.1°C. This relatively mild weather would not cause much condensation. However, an exceptionally cold period occurred during the last week of January 1990. Outdoor temperatures reached almost -37°C, resulting in streaking condensation.

The supply air temperature was initially set at 17°C to minimize electrical consumption. However, the indoor air temperature was consistently set at 24°C to 25°C. Accustomed to a relatively warm indoor temperature, the 17°C supply air seemed cool to the occupants; consequently, they thought the make-up air heater unit was inoperative. This notion was reinforced further by the excessive condensation experienced during the cold period in late January.

To resolve this situation, the housing officer adjusted the make-up air unit by increasing fan speed and resetting the supply air temperature to 22°C which prevented any further discomfort to the occupants. When the fan speed was increased, the relative humidity decreased to 40% as shown in table 2. The hygrothermograph charts in Figure 18 below clearly show the indoor relative humidity before and after the installation of the make-up air unit.

(b) Energy Consumption

An electric resistance heater will add to the operating costs of the house since any ventilation involving the introduction of cold air causes heat loss.

ASHRAE Handbook of Fundamentals [35], 1981, provides the following equation for estimating energy cost:

$$E = \frac{H_L \times D \times 24}{Dt \times k \times V} (C_D)$$

where:

E = energy consumption required to compensate for ventilation losses for the estimated period (kW.h)
H_L = design heat loss (W) 1.1 x airflow rate x temperature difference
D = degree day (°C), 6302 for Slave Lake
Dt = design temperature difference (°C)
k = a correlation factor which includes the effects of rated full load efficiency, part-load performance, oversizing and energy conservation devices
V = heating value of fuel, units consistent with H_L and E
C_D = empirical correction factor for heating effect vs. 18.3°C degree days.

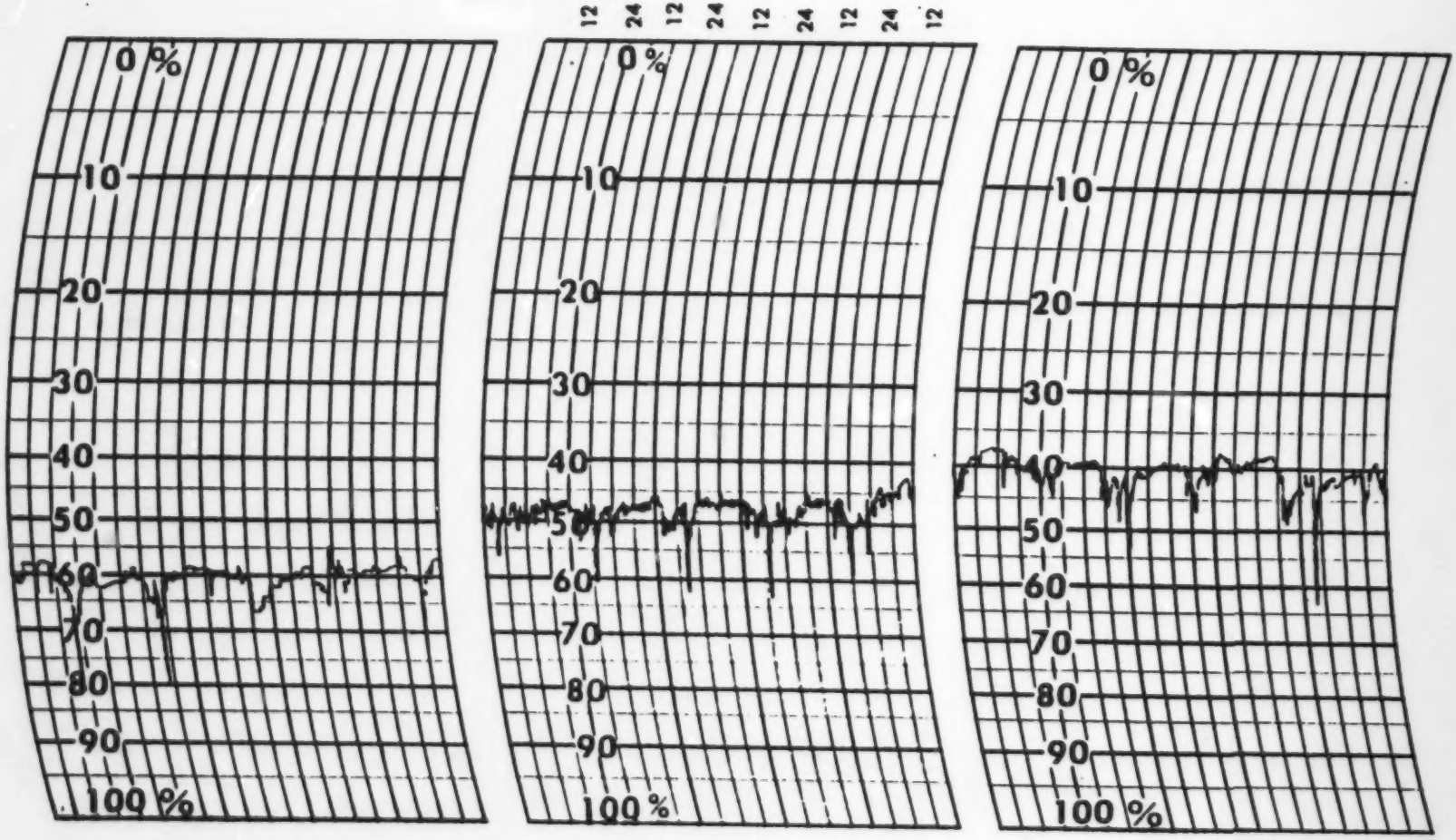
Assume that 30 L/s outside ventilation air is introduced into the house at 18°C, and the outdoor design temperature for Gift Lake is -39°C. To compensate for heat loss due to ventilation the amount of propane used annually is:

$$H_L = 1.1 \times 30 \times 57 = 1.881 \text{ kW.h}$$

$$E = \frac{1.881 \times 6302 \times 24}{57 \times 0.55 \times 50\ 402} \times 0.7 \times (3600 \text{ kJ/kW})$$

$$= 454 \text{ kg of propane.}$$

If the cost of propane is approximately $0.15/kg, the annual cost is 454 x $0.15 = $68.10.



NO VENTILATION
(JANUARY 1989)

MAKE-UP AIR AT 50 L/s
(JANUARY 1990)

MAKE-UP AIR AT 75 L/s
(FEBRUARY 1990)

Fig. 18: Relative Humidity in House B Before and After Installation

When using electricity to heat make-up air, the annual electrical consumption is:

$$E = \frac{1.881 \times 6302 \times 24}{57 \times 1 \times 1} \times 0.7$$

$$= 3494 \text{ kW}$$

If the electrical energy cost is $0.0626/kW plus 3.96% municipal tax less 20% income tax, the rate is $0.0519/kW. Annual electrical energy cost is 3494 x $0.0519 = $181.00 per year. The electricity consumed by the fan adds another $28.00 per year for a total operating cost of $209.00.

The cost difference between heating the ventilating air using electricity and propane is $209.00 - ($68.10 + $28.00) = $112.90.

Actual electrical energy consumption (extrapolated for the year) for powering the electric element and fan is $160.00 as seen in Table 3.

The intake air required will vary depending on the amount of moisture generated in each house. In House "B", excessive moisture from nine occupants and their activities contributed heavily to the higher interior humidity. Most homes have fewer occupants, therefore, the additional cost of electrical energy would not be as high.

TABLE 3: ELECTRICAL CONSUMPTION OF MAKE-UP AIR UNIT (House "B")

DATE 1988/89	KW reading cumulative	consumption for period	days	cost /day
Feb. 15 (MUA #1)*	0			
May 12 (MUA #2)	536	536	86	32¢
Sep. 21 (MUA #3)	2117	1581	132	62¢
Jan. 17 (increase fan)	2910	793	118	35¢
June 8 (disconnected)	4038	1128	142	41¢
		4038	478	

* MUA #1 = make-up air unit, prototype #1.

5.4.4 Findings

The make-up air unit as represented by prototype #3 proved to be a most effective means of reducing indoor humidity levels. The forced air unit provides controlled amounts of ventilation, maintains an acceptable level of humidity, and preheats the make-up air to prevent occupant discomfort. Furthermore, the system is completely automatic.

Even when the amount of electrical power consumed to heat the make-up air is considered, the extra cost of electrical energy is less than 45¢ per day. This cost is minimal when compared to the advantages of healthier indoor air and reductions in condensation damage.

Contribution from the solar preheat supply air device was not monitored as it was beyond the scope of this project. However, given a collector area of 1.2 m^2, and a solar contribution for the five winter months at 30% efficiency of 65 MJ/m^2, the collector could collect 65 MJ/m^2 X 1.2 m^2 X \$0.0519/kW X 3.6 (conversion) = \$14.57 worth of equivalent electric heat. The main advantage of the device, however, was to raise the air intake above the snow cover and minimize the entry of dust.

5.5 House "C", Wabasca: (Natural Stack Ventilation)

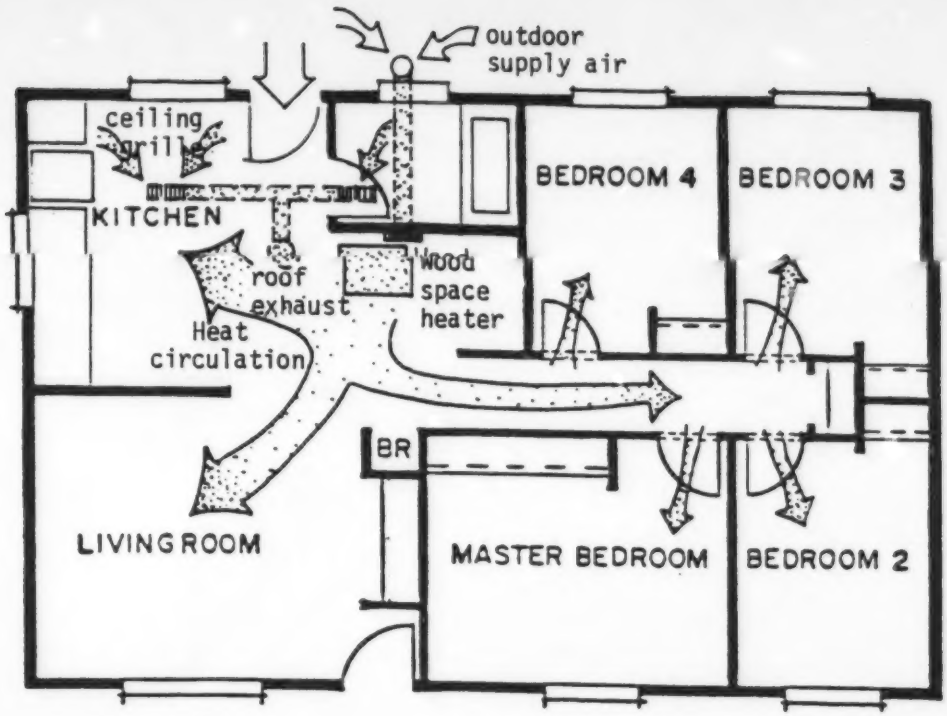
5.5.1 Site Description and Problem Identification

On May 10, 1989, House "C", a 96.6 m² (1040 sq.ft.) bungalow (see figure 19) in Wabasca was visited for the first time. House C had been selected by RHAP housing officers as a typical house which had severe condensation damage. A hygrothermograph had been recording the relative humidity and temperature conditions since the end of 1988. This house was representative of the many remote dwellings that exist without plumbing or sewage disposal. Space heating was provided by a wood burning heater located in the kitchen near the corridor leading to the bedrooms.

The house was built in 1987, but condensation damage made the house seem older. Condensation damage included dust marks, water stains, mold growth and damaged drywall, particularly under window sills in the bedrooms.

The hygrothermograph charts suggested the relative humidity varied from 32% to 100% with a normal range of 40% to 70%. Lower relative humidity levels were misleading because indoor temperatures fluctuated from the use of a manually operated wood heater. Indoor temperatures varied from 15°C to 44°C causing lower relative humidity readings at the higher temperatures.

The correlation between relative humidity and indoor air temperature is illustrated in the hygrothermograph charts shown in figures 20 and 21. The occupants normally filled the heater with wood at about 21:00. The temperature would rise to almost 40°C and then slowly drop throughout the evening. By 08:00, the temperature had dropped to about 15°C and the heater would then be refuelled. Figure 22 below, extracted from the hygrothermograph charts, shows that the relative humidity followed an inverse profile to that of the temperature.



FLOOR PLAN

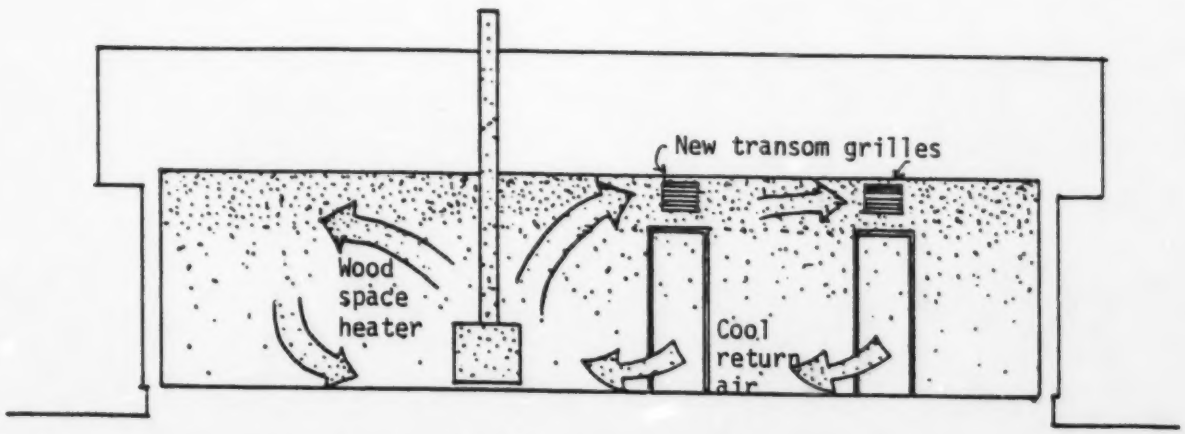


Fig. 19: Warm Air Circulated to Bedrooms Through Natural Convection, House C, Wabasca

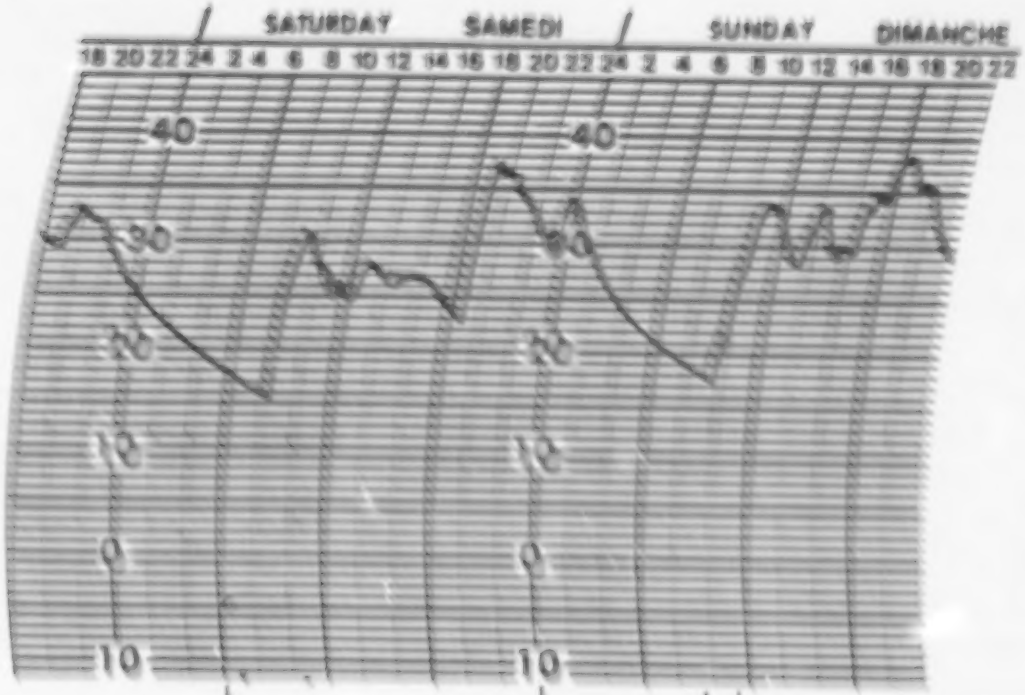


Fig. 20: Indoor Air Temperature Before Modification - House "C"

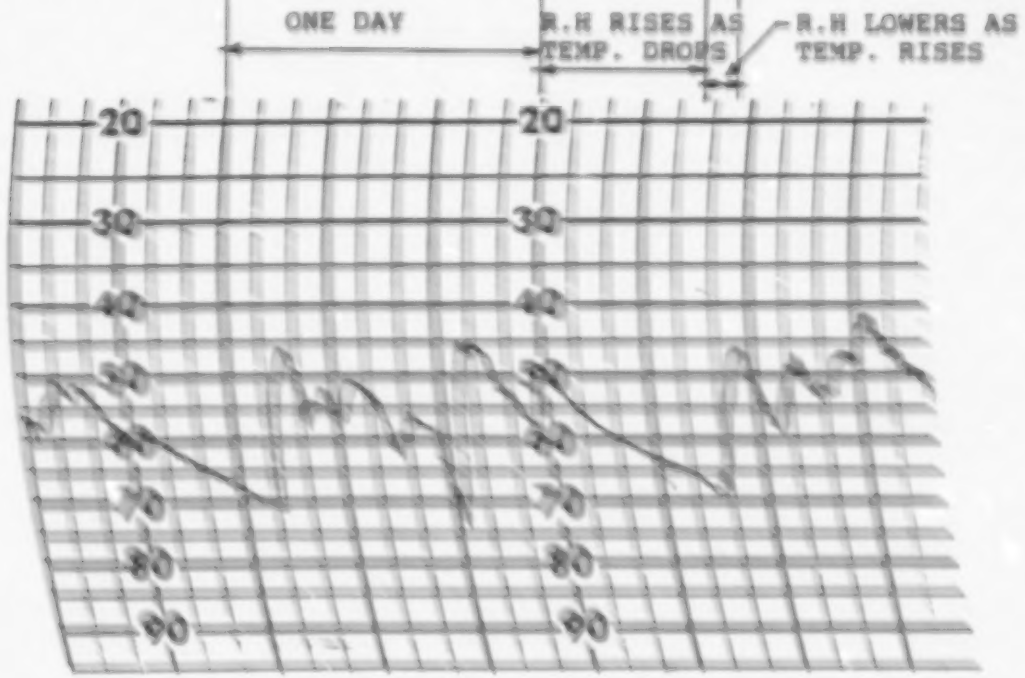


Fig. 21: Relative Humidity Profile in House "C"

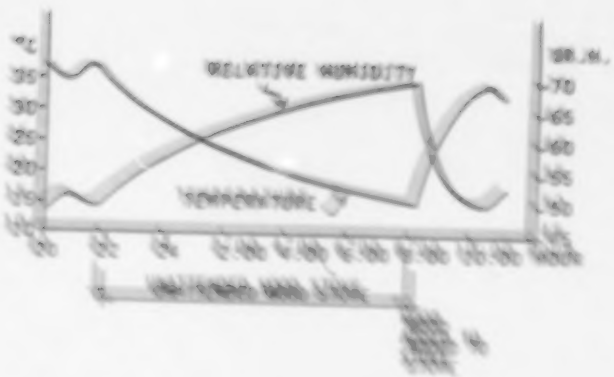


Figure 22: Typical Temperature and Relative Humidity Profiles in House "C".

The following factors contributed to the high humidity levels in the home:

- a large number of residents (8 children, 2 adults)
- uncovered water cistern and waste-water drum
- extensive food boiling
- drying meats and firewood
- clothes dryer exhaust vented directly into crawl space.

5.5.2 Mitigation

In typical wood heated houses the indoor relative humidity is high because of excessive moisture-generating activities such as storing and drying wood fuel. Furthermore, the system does not have the passive air ducts found in the typical furnace system which mitigate the problem. This leads to the need for extensive ventilation.

Houses heated by wood stoves naturally create a slightly negative air pressure in the house. If exhaust ventilation increases this negative air pressure, backdrafting problems in the chimney flue can occur. Backdrafting can be avoided by balancing the exhausted air with a fresh air supply.

In House "C", a passive ventilation system that depends on the natural stack effect to exhaust air out of the house was installed. Two ceiling vents were installed in the kitchen and bathroom (see figure 23). The ceiling vents exhaust humid air through an existing

turbine ventilator mounted on the roof which helps to extract more air from the house.

To prevent cold drafts from backing down the exhaust vent and to reduce ventilation heat loss, a dehumidistat opens a damper only when indoor relative humidity reaches 30%.

Balancing cold fresh air was ducted into the house through an insulated duct located in the crawl space. To prevent snow from clogging the fresh air intake, the intake grille was extended 8 meter above outside grade. To avoid occupant discomfort, cold outdoor supply air must be preheated before discharging into the house. Otherwise, the occupants may, understandably, plug up the register. In House "C", cold outdoor air is discharged into the house behind the wood heater, where it is preheated to minimize occupant discomfort.

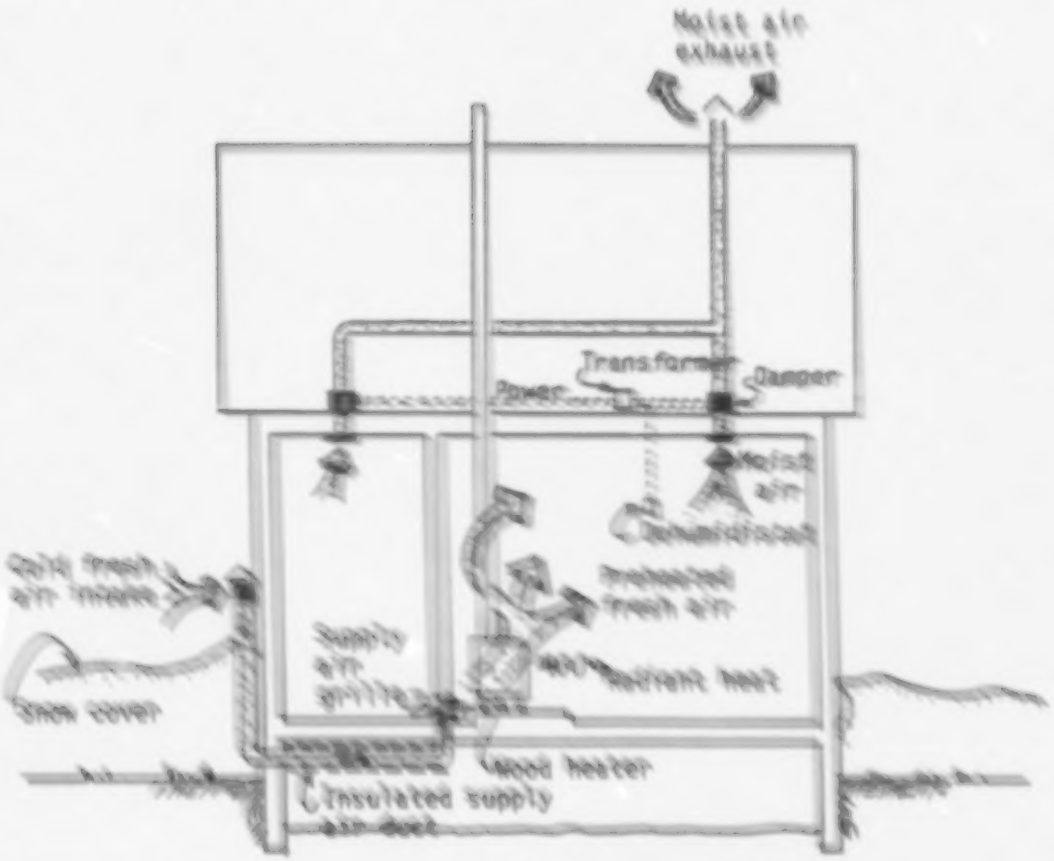


Figure 23: Natural Stack Ventilation - House "C"

Heating with a wood stove caused House "C" to undergo extreme temperature fluctuations, heat stratification, and reduced air circulation. The bedrooms are located down a long corridor away from the wood stove. The design of the house and poor air circulation resulted in an overheated living room and kitchen, but very cold bedrooms. It was necessary to circulate warm air from the wood heater to the bedrooms to reduce condensation.

three holes were cut in the transoms in each bedroom. The objective was to allow the stratified heated air to circulate into the bedrooms (see figure 19 on page 43). The clothes dryer exhaust vent that was exhausting into the crawl space was re-directed to the exterior. The modifications were completed on December 12, 1989.

3.3.3 Findings

The modifications to House "C", including venting the clothes dryer to the exterior, were successful in increasing ventilation and lowering indoor humidity. Results indicate that the passive ventilation system reduced the indoor relative humidity from 55% to 45% (Table 4). At 45% relative humidity, condensation will remain a problem, but the rate of condensation formation and subsequent damage will be less. However, even the limited passive ventilation reduced the odour and stale air previously associated with an unvented house.

TABLE 4: JANUARY INDOOR TEMPERATURES AND RELATIVE HUMIDITIES (House "C")

DATE	AVERAGE INDOOR TEMPERATURE*	LOW R.H.	HIGH R.H.	AVERAGE R.H.
Jan/89	20°C	35%	65%	55%
Jan/90	20°C	30%	55%	45%

* Temperatures fluctuate wildly, ranging from 15°C to 40°C.

Intake air is preheated by the wood stove to improve occupant comfort, but only if the wood stove is in use. Cold drafts will occur whenever the wood stove is not maintained. Because of additional ventilation, more wood will be needed to maintain the same temperature level inside the house.

6.0 CONCLUSION

Three retrofit measures for lowering indoor humidity were investigated in this study. Results indicate that while all three were able to reduce humidity, each had advantages and disadvantages when used in the northern setting being investigated.

It was concluded that the make-up air unit demonstrated in House "B", was the best solution.

> **The make-up air unit is dependable and has sufficient airflow and heating capacity to lower the indoor relative humidity to 30%.**

Depending on humidity levels, the make-up air unit controls the amount of fresh air supplied to the house. By varying the discharge temperature, the make-up air unit maximizes occupant comfort and minimizes electrical energy consumption. However, it is also important to equip the house with bathroom and kitchen exhausts to help relieve positive pressure created by supplying outside air. Although not part of this study, the make-up air unit was also capable of counteracting chimney backdrafting caused by exhaust devices. Further, it can minimize radon gas and other external air-borne pollutants while maintaining good indoor air quality.

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